10/553316
JC09 Rec'd PCT/PTO 17 OCT 2005

ALUMINUM ALLOY PLATE EXCELLENT IN PRESS FORMABILITY AND CONTINUOUS RESISTANCE SPOT WELDABILITY AND METHOD FOR PRODUCTION THEREOF

TECHNICAL FIELD

The present invention relates to an aluminum alloy plate with excellent press-formability and continuous resistance spot weldability which is useful as a structural material for forming the outer panels of products such as household appliances or automobiles that are assembled by resistance spot welding before or after press molding.

BACKGROUND ART

The structural materials and the outer panels of products of household appliances and automobiles are pressed firstly forming, then resistance spot welded to assemble the products.

Al-Mg-Si type alloy plates (JIS 6000) show a relatively attractive surface appearance after press forming, and are therefore used in various types of outer panels and structural materials, but require good press-formability due to the diversity of product shapes.

Additionally, there is a demand for increases in the number of consecutive welds capable of being performed by resistance spot welding in order to reduce the times the electrodes are replaced during resistance spot welding work.

Japanese Patent Application, First Publication No. S62-207851 describes a method for manufacturing a rolled plate such as a body plate with good formability, comprising steps of preparing an aluminum alloy melt containing 0.4-2.5% of Si, 0.1-1.2% of Mg, one or

more types chosen from among 1.5% or less of Cu, 2.5% or less of Zn, 0.3% or less of Cr, 0.6% or less of Mn and 0.3% or less of Zr, with the remainder consisting of Al and unavoidable impurities; continuously casting the melt into 3-15 mm thick slabs; performing cold rolling; and then performing a solution heat treatment and quenching.

Additionally, Japanese Patent Application, First Publication No. 2001-262264 describes Al-Mg-Si type aluminum alloy plates used for automobile panels with good bendability. For example, the publication discloses an Al-Mg-Si type aluminum alloy plate with excellent toughness and bendability, basically comprising 0.1-2.0% of Mg, 0.1-2.0% of Si and 0.1-1.5% of Fe in % by mass, with the remainder consisting of Al, wherein the maximum size of Fe and Si containing compounds is 5 μm or less, and the average grain size is 30 μm or less. Additionally, it discloses an Al-Mg-Si type aluminum alloy plate with excellent toughness and bendability, basically comprising 0.1-2.0% of Mg, 0.1-2.0% of Si, 0.1-1.5% of Fe and 2.0% or less of Fe in % by mass, with the remainder consisting of Al, wherein the maximum size of Fe, Si and Cu containing compounds is 5 μm or less, and the average crystal grain size is 30 μm or less. Furthermore, it discloses an Al-Mg-Si type aluminum alloy plate with excellent toughness and bendability such as those described above, further comprising at least one element chosen from the group consisting of 1.0% or less of Mn, 0.3% or less of Cr, 0.3% or less of Zr, 0.3% or less of V and 0.03% or less of Ti.

The technique described in Japanese Patent Application, First Publication No. S62-207851 uses a twin-roller casting process with casting at a cooling rate of at least 100 °C/sec, so that the size of intermetallic compounds that crystallize during casting is small, as a result of which the number of relatively large compounds that affect the grain

size at recrsytallization is not sufficient, so that the grain size after solution heat treatment is large, thus degrading the press-formability, and the number of continuous resistance spot welds is reduced.

The technique disclosed in Japanese Patent Application, First Publication No. 2001-262264 uses a continuous casting process, with casting at a cooling rate of at least 10 °C/sec, but in the examples, a maximum cooling rate of 30 °C/sec is used. Due to the slow cooling rate, the size of intermetallic compounds that crystallize during casting is large, as a result of which the number of relatively large compounds that affect the grain size at recrsytallization is not sufficient, so that the grain size after solution heat treatment is large, thus degrading the press-formability and reducing the number of continuous resistance spot welds .

DISCLOSURE OF THE INVENTION

The purpose of the present invention is to offer an aluminum alloy plate with excellent press-formability and continuous resistance spot weldability, and a manufacturing process thereof.

The present inventors achieved the present invention on the basis of the discovery that by selecting the optimum range for the cooling rate when casting a melt within an appropriate composition range, it is possible to optimize the size and number of intermetallic compounds that crystallize, so as to obtain excellent press-formability and continuous resistance spot weldability in an aluminum alloy plate after a solution heat treatment.

That is, the present invention offers an aluminum alloy plate with excellent

press-formability and continuous resistance spot weldability comprising, in % by mass, 0.3-1.0% of Mg, 0.3-1.2% of Si, 0.10-1.0% of Fe and 0.05-0.5% of Mn; where Fe + Mn ≥ 0.2%; the remainder consisting of Al and unavoidable impurities; wherein an average value of recrystallized grain size is 25 μm or less; and there are at least 5000 particles/mm^2 of intermetallic compounds with a circle-equivalent diameter of 1-6 μm.

The present invention excels in press-formability and continuous resistance spot weldability due to the fineness of the recrsytallization grain size and the large number of compounds of optimum size.

The strength can be further improved by making the above composition contain Cu in an amount of 0.5-1.0%.

The recrystallization grain size can be made finer and the strength further improved by making the above composition contain Zr in an amount of 0.1-0.4%.

Casting cracks can be reliably prevented from occurring during casting by making the above composition contain Ti in an amount of 0.05% or less, or Ti in an amount of 0.05% or less and B in an amount of 0.01% or less.

A second aspect of the present invention is a method of manufacturing an aluminum alloy plate with excellent press-formability and continuous resistance spot weldability, comprising steps of pouring a melt consisting of the above-claimed composition into an opposing rotating belt cast that is forcibly cooled; casting the melt at a cooling rate of 40-90 °C/sec to form a 5-10 mm thick slab; drawing said slab from the side opposite the side where the melt was poured; rolling directly or after winding into a coil; and subjecting to a solution heat treatment.

A large number of compounds of optimum size can be crystallized by casting the

alloy melt at an optimal cooling rate when casting, thereby refining the recrystallization grain size to result in aluminum alloy plates with excellent press-formability, and continuous spot weldability is good.

BEST MODE FOR CARRYING OUT THE INVENTION

Herebelow, the preferable amounts of the respective components contained in the aluminum alloy plates of the present invention shall be described, followed by the reasons for the upper and lower limits. In this specification, all quantities expressed in % refer to percentage by mass except where indicated otherwise.

[Mg: 0.3-1.0%]

[Si: 0.3-1.2%]

Mg and Si are added to improve the strength and to provide press-formability. When the concentration is less than the indicated lower limit, the effects are inadequate, and when more than the indicated upper limit, the press -formability deteriorates.

[Fe: 0.10-1.0%]

[Mn: 0.05-0.5%]

[Fe + Mn ≥ 0.2%]

By adding Fe and Mn together and keeping Fe + Mn ≥ 0.2%, it is possible to crystallize a large quantity of compounds of a specific size, increase the amount recrystallized, and the size of the recrystallized grains becames small. Both elements have little effect when their concentration are less than the respective lower limits, and when their concentrations exceed the upper limits, cause bulky crystals to occur, so that surface blemishes such as streaks can appear during cold rolling and the press-formability also

deteriorates. Mn does not crystallize into an intermetallic compound of desirable size and number unless it coexists with Fe. The total quantity of Fe and Mn is more preferably such that Fe + Mn ≥ 0.3%.

[Cu: 0.5-1.0%]

Cu is added to further improve the strength and press-formability. When the concentration is less than the lower limit, its effect is small, and when the quantity exceeds the upper limit, the corrosion resistance is degraded.

[Zr: 0.1-0.4%]

Zr promotes the crystallization of the intermetallic compound Al_3Zr, further induces crystallization of many compounds of specific size to increase the number of recrystallized nuclei, and thereby make the size of the recrsytallized grains smaller, so as to improve press-formability. The effect is lost when the concentration is less than the lower limit, and when the quantity exceeds the upper limit, large compounds are formed so that the rollability is reduced.

[Ti: 0.05% or less; or Ti: 0.05% or less and B: 0.01% or less]

Rapid cooling during casting of the melt can cause casting cracks to occur, and the addition of Ti or Ti and B can prevent such cracks. It is possible to add either Ti alone at a quantity of 0.05% or less, or to also add 0.01% or less of B to obtain a composite with Ti, in which case there is a synergistic effect. The effect is most apparent when the lower limit of the Ti is at least 0.002%, and the lower limit of B is at least 0.0005%.

The unavoidable impurities can come from the base aluminum, scrap and ingot jigs or the like, some of the typical elements including Cr, Ni, Zn, Ga and V. Since Cr is added to prevent stress corrosion of the Al-Mg alloy, it can easily be introduced from scrap,

but is allowable in the present invention if less than 0.3%. The quantity of Ni should be held to less than 0.2%, that of Ga and V respectively less than 0.1%, and that of any other unavoidable impurities to less than 0.3% in order to maintain the formability.

[Average Recrystallization Grain Size 25 μm or less]

If the recrystallized grains of plates after the solution heat treatment are small, then they can be formed without damage even if the press draft is set high and the drawing height is set high. If the grains size exceeds the upper limit, the effect is lost, and the surface appearance after pressing is not good. The recrystallization grain size should preferably be 20 μm or less, and 15 μm or less.

[5000/mm² Intermetallic Compounds with Circle Equivalent Diameter of 1-6 μm]

Intermetallic compounds having a circle equivalent diameter of 1-6 μm are of a size promoting the accumulation the integration of dislocations during cold rolling and having an effect of refining the recrystallized grains, so that if the size and number is less than the lower limit, the dislocation accumulation rate is low, and if the number is less than 5000 particles/mm², fine recrystallized grains of a preferable size cannot be obtained. Additionally, if the size exceeds the upper limit, the large compounds can cause streaks or cracks during rolling and thereby lower the rollability. Additionally, with the state of the compounds as described above, a erosion effect occurring due to a reaction between the copper electrodes and the Al when performing continuous resistance spot welding can be prevented, thus reducing the number of times the electrode needs to be replaced and improving the productivity. The quantity of the compounds is more preferably at least 6000 particles/mm²

Next, a preferable process for manufacturing the aluminum alloy plates of the

present invention shall be described.

The melt is prepared by adjusting the composition, degassing, settling, making fine adjustments of the composition as needed, adding Ti or Ti and B as a mother alloy and casting. When casting, the melt is poured into forcibly cooled rotating belters facing each other, with the cooling rate 40-90 °C/sec, to form a 5-10 mm thick slab, then drawing the slab from the opposite side to where the melt was poured, to roll it directly or after winding into a coil.

Continuous casting processes include a twin -roller casting process of pouring the melt between forcibly cooled rotating rollers that are facing each other, rapidly cooling the melt on the roller surfaces, and continuously withdrawing thin slabs from the opposite side, and a twin-belt casting process of pouring the melt between forcibly cooled rotating belts that are facing each other, rapidly cooling the melt on the belt surfaces, and continuously withdrawing thin slabs from the opposite side.

The twin-roller casting process has a cooling rate during casting of at least 300 °C/sec which is considerably high, while the size of compounds in the resulting slab are small and the plates of the present invention are not obtained. On the other hand, the twin-belt casting process involves rapidly cooling the melt on the belt surface, but the cooling rate is not as high as with the twin-roller casting process.

In the present invention, the casting conditions of the twin-belt casting process are adjusted so as to make the melt cooling rate 40-90 °C/sec (at a position of 1/4 thickness of the slab), so as to form more than 5000 particles/mm^2 of intermetallic compounds with a circle-equivalent diameter of 1-6 μm in the final plates. If the melt cooling rate is less than 40 °C/sec, larger compounds are crystallized, causing a deficiency of compounds in the

above-defined size range, so that the recrystallized grains are not refined and plates with excellent press-formability cannot be obtained. Additionally, at more than 90 °C/sec, fine compounds are crystallized, causing a reduction of compounds in the above-defined size range, so that a plate with refined recrsytallized grains cannot be obtained.

A slab obtained by a twin-belt casting process is cold-rolled to form a plate of a desired thickness, which undergoes a solution heat treatment and is recrsytallized. At this time, it is possible to provide an anneal during the cold rolling step, but the rolled plate provided for the solution heat treatment has at least a cold reduction of 55%. The solution heat treatment is performed in a continuous annealing furnace. The heating temperature is at least 500 °C, the cooling rate to 100 °C is set to at least 1 °C/sec. The recrystallized grains of the rolled plates that have undergone the solution heat treatment have an average grain size of 25 μm or less due to the size and number of the intermetallic compound and the reduction. Such plates can be used either as they are, or after passing through a skin pass or leveler of about 1-5% in order to obtain flatness.

EXAMPLES

An aluminum alloy melt with the composition shown in Table 1 was degassed, settled, then the melt was cast into a 7 mm thick slab at cooling rates of 50 °C/sec and 75 °C/sec in a twin-belt continuous casting process. The slab drawing speed was 8 m/min. This slab was cold-rolled, and subjected to an intermediate annealing treatment as needed to form a 1 mm thick plate. Next, this plate was subjected to a solution heat treatment, and after the treatment, the size and number of intermetallic compounds, recrsytallization grain size, 0.2% yield strength (YS), ultimate tensile strength (UTS), elongation (EL), deep drawing height and resistance spot weldability were measured. The results are shown in

Table 3.

The deep drawing conditions and evaluation conditions for the resistance spot weldability were as shown below.

(Deep Drawing Test)

Mold Used	Punch	diameter 50 mm
		shoulder R 5 mm
	Dies	inner diameter 52.5 mm
		shoulder R 8 mm
Blank		diameter 112.5 mm

(Evaluation Conditions for Resistance Spot Weldability)

Single Phase Rectifier Type Spot Welding Machine

Electrode   Cu - 1% Cr Alloy

Pressure   400 kgf

Determination of Welding Current: Minimum welding current where tensile shear strength satisfies grade A average standard as defined by JIS Z3140.

Consecutive welding spots: Number of welding consecutively with strength exceeding grade A average standard when continuous spot welding using the welding current values determined above and with the above welding conditions.

A: at least 500 consecutive hits

B: at least 200 less than 500 consecutive hits

C: less than 200 consecutive hits

TABLE 1 Alloy Composition (units in % by mass)

Alloy No.	Mg	Si	Fe	Mn	Cu	Zr	Ti	B	Comments
A	0.6	0.8	0.12	0.1	-	-	0.02		Present Invention
B	0.4	0.8	0.2	0.2	-	-	0.02		Present Invention
C	0.5	0.7	0.2	0.2	-	-	0.02		Present Invention
D	0.5	0.8	0.2	0.2	-	-	0.01		Present Invention
E	0.6	0.8	0.7	0.1	-	-	0.02		Present Invention
F	0.5	0.9	0.15	0.3	-	-	0.02		Present Invention
G	0.5	0.7	0.2	0.2	0.6	-	0.02		Present Invention
H	0.5	0.7	0.2	0.2	-	0.15	0.02		Present Invention
I	0.5	0.7	0.2	0.2	0.7	0.12	0.02		Present Invention
J	1.2	0.7	0.2	0.2	-	-	0.02		Comparative Example
K	0.5	1.4	0.2	0.2	-	-	0.02		Comparative Example
L	0.5	0.7	0.05	0.2	-	-	0.02		Comparative Example
M	0.5	0.7	1.5	0.2	-	-	0.02		Comparative Example
N	0.5	0.7	0.2	0.7	-	-	0.02		Comparative Example
O	0.5	0.7	0.2	0.2	1.2	-	0.02		Comparative Example
P	0.5	0.7	0.2	0.2	-	0.5	0.02		Comparative Example

(Note) Remainder: Al and impurities.
Underlined values are outside the range of the present invention.

TABLE 2 Manufacturing Process

No.	Alloy No.	Cast Methods/ Slab Thickness (mm)	Cooling Rate (°C/sec)	Hot Roll (mm)	Cold Roll (mm)	Interm. Anneal Temp (°C)/ hour (h)	Cold Roll (mm)	Soln. Heat Tr. Temp. (°C)	Comm.
1	A	twin belt/7	50	-	-	-	1	550 °C	Pres Inv
2	B	twin belt/7	50	-	-	-	1	550 °C	Pres Inv
3	C	twin belt/7	50	-	-	-	1	550 °C	Pres Inv
4	D	twin belt/7	50	-	-	-	1	550 °C	Pres Inv
5	E	twin belt/7	50	-	-	-	1	550 °C	Pres Inv
6	F	twin belt/7	50	-	-	-	1	550 °C	Pres Inv
7	G	twin belt/7	50	-	-	-	1	550 °C	Pres Inv
8	H	twin belt/7	50	-	-	-	1	550 °C	Pres Inv
9	I	twin belt/7	50	-	-	-	1	550 °C	Pres Inv
10	C	twin belt/7	50	-	2.5	360/2	1	550 °C	Pres Inv
11	B	twin belt/7	75	-	-	-	1	550 °C	Pres Inv
12	J	twin belt/7	50	-	-	-	1	550 °C	Comp Ex
13	K	twin belt/7	50	-	-	-	1	550 °C	Comp Ex
14	L	twin belt/7	50	-	-	-	1	550 °C	Comp Ex
15	M	twin belt/7	50	-	-	-	1	550 °C	Comp Ex
16	N	twin belt/7	50	-	-	-	1	550 °C	Comp Ex
17	O	twin belt/7	50	-	-	-	1	550 °C	Comp Ex
18	P	twin belt/7	50	-	-	-	1	550 °C	Comp Ex
19	B	twin belt/20	20	3	-	-	1	550 °C	Comp Ex
20	B	twin belt/3	150	-	-	-	1	550 °C	Comp Ex

(Note) Underlined values are outside the range of the present invention.

TABLE 3 Microstractures and Properties

No.	Density of Intermetallic Compound (/mm²)	Grain Size (μm)	Tensile Properties			Deeping Drawing Height(mm)	Resistance Spot Weldability	Comments
			0/2%YS (MPa)	UTS (MPa)	EL (%)			
1	5917	12	130	238	28	14.5	B	Present Invention
2	6812	11	118	222	29	14.1	A	Present Invention
3	7185	10	124	228	28	14.3	A	Present Invention
4	7726	9	132	239	30	14.7	A	Present Invention
5	11254	7	145	249	27	14.2	A	Present Invention
6	6917	11	128	235	29	14.8	A	Present Invention
7	7435	10	135	264	29	14.9	A	Present Invention
8	7982	8	126	230	29	14.8	A	Present Invention
9	8013	8	137	266	30	14.9	A	Present Invention
10	6725	15	114	219	27	14.0	A	Present Invention
11	7820	9	122	230	30	15.1	A	Present Invention
12	7543	11	140	252	24	13.5	A	Comp. Example
13	7521	9	131	251	23	13.6	A	Comp. Example
14	<u>3924</u>	<u>26</u>	112	215	26	13.5	C	Comp. Example
15	36721	6	133	241	21	13.5	A	Comp. Example
16	7820	11	134	248	20	13.7	A	Comp. Example
17	7541	9	160	288	22	13.8	A	Comp. Example
18	8783	7	142	235	21	13.9	A	Comp. Example
19	<u>2215</u>	<u>29</u>	109	215	20	12.5	C	Comp. Example
20	<u>3272</u>	<u>26</u>	113	218	22	12.8	C	Comp. Example

(Note) A: at least 500 consecutive hits
B: at least 200 less than 500 consecutive hits
C: less than 200 consecutive hits
Underlined values are outside the range of the present invention.
Recrystallized grain size was measured by liner intercept method.

From the results in Tables 1-3, it is apparent that the examples of the present invention (Sample Nos. 1-11) have a high deep drawing height and excel in press-formability, as well as having many consecutive hits and excelling in continuous resistance spot weldability. On the other hand, the comparative examples (Samples Nos. 12-18) whose compositions are outside the range of the present invention have a low deep drawing height and poor press-formability, while the comparative examples (Samples Nos. 14, 19, 20) with few intermetallic compounds with a circle-equivalent diameter of 1-6 μm and a large grain size had few consecutive hits and poor continuous resistance spot weldability.

As described above, the aluminum alloy plates according to the present invention

excel in press-formability and continuous resistance spot weldability, and surface appearance after press is good, enabling continuous assembly by resistance spot welding, therefore productivity is high. This 6000 type alloy plate also has higher strength improves in a baking step after coating or the like, so as to have excellent industrial value in a wide range of applications such as in the body panels of automobiles.